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Compilation of Measured Nutrient Load Data for Agricultural Land Uses in the US[1]

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ABSTRACT

Measured field-scale data are increasingly utilized to guide policy and management decisions based on comparative pollutant load information from various land management alternatives. The primary objective of this study was to compile measured annual nitrogen (N) and phosphorus (P) load data representing field-scale transport from agricultural land uses. This effort expanded previous work that established an initial nutrient export coefficient data set. Only measured annual N and P load data published in scientific peer-reviewed studies were included in the present compilation. Additional criteria for inclusion were: spatial scale (field- or farm-scale, minimum 0.009 ha), land use (homogeneous either cultivated agriculture or pasture/rangeland/hay), natural rainfall (not rainfall simulation), and temporal scale (minimum one year). Annual N and P load data were obtained from 40 publications resulting in a 163-record database with more than 1100 watershed years of data. Basic descriptive statistics in relation to N and P loads were tabulated for tillage management, conservation practices, fertilizer application, soil texture, watershed size, and land use (crop type). The resulting MANAGE database "Measured Annual Nutrient loads from AGricultural Environments" provides readily accessible, easily queried watershed characteristic and nutrient load data and establishes a platform suitable for input of additional project-specific data.

KEYWORDS: Database, nitrogen, nonpoint source pollution, phosphorus, water quality

INTRODUCTION

Growing demand for land use-specific nutrient export information to inform regulatory and educational programs and to support water quality modeling has highlighted the need for a comprehensive database containing measured nutrient loss data. Water quality protection programs require comparative nutrient export information for land management alternatives to prevent excess nutrient loading and the resulting impacts of accelerated eutrophication and degraded aquatic habitat in downstream water bodies. Although estimated values from watershed models, regional relationships, or professional judgment can provide this information, measured field-scale data are necessary to substantiate and/or improve these estimates.

Field-scale nutrient load data are also needed to better understand nutrient transport mechanisms and sources of variability as affected by soil, land use, climate, topography, and management

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[1] The MANAGE database (v1 and v2) are available at no cost from the authors or online at http://www.ars.usda.gov/spa/manage-nutrient. Future, expanded versions will be available as updates are completed. Mention of trade names or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the United States Department of Agriculture.

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(Kissel et al. 1976, Sharpley et al. 2002). Small watersheds and field plots established to collect runoff from natural precipitation events are well suited for these investigations (Vervoort et al. 1998, Gilley and Risse 2000). Measured nutrient transport data are necessary to support nonpoint source model development, calibration, and evaluation. Models are an efficient method to evaluate nutrient loading mechanisms under various conditions, but they rely on monitoring data to improve performance and reduce uncertainty (Sharpley et al. 2002). According to Sharpley et al. (2003), data are also urgently needed to test and validate nutrient management tools, such as the P Index that was designed to assess risk of phosphorus loss from individual agricultural fields (Lemunyon and Gilbert 1993). Where such data are available, they should be applied to the fullest extent possible to support ongoing modeling efforts (Sharpley et al. 2002). However, measured project- or site-specific data are typically not available due to the considerable time, expense, and effort required to collect field measurements (Beaulac and Reckhow 1982, Gilley and Risse 2000). In these situations, a comprehensive database containing measured field-scale nutrient loss data and corresponding watershed characteristic information would be a valuable resource.

Although several excellent data management systems are currently available for hydrology and water quality information, they were designed to manage a wide range of data types collected on various scales. These systems include the EPA Storage and Retrieval (STORET), USGS National Water Quality Assessment (NAWQA) and National Water Information System (NWISW), similar state-specific systems, and the recently developed Watershed Monitoring and Analysis database (Carleton et al. 2005). These powerful tools assist in the storage, quality control, manipulation, retrieval, and transfer of data, but they do not typically provide measured field-scale data with corresponding watershed characterization information. No comprehensive electronic database populated with field-scale nutrient export data is currently available.

The initial effort to gather and compile such data was made in the early 1980's. In a study of lake eutrophication, researchers compiled measured nutrient export data for various sources including: forest, urban, crop land, pasture and grazing land, mixed agricultural areas, feedlot and manure storage areas, atmospheric contribution, septic tanks, and sewage treatment plants. The resulting reports utilized all available appropriate monitoring information and formed an excellent basis of knowledge on the magnitude and variability of annual nutrient losses (termed export coefficients) for a variety of land uses (Reckhow et al. 1980, Beaulac 1980, Beaulac and Reckhow 1982). This information, however, has not been updated with data collected in the last 25 years or re-configured in an electronic format.

Based on the need for a current field-scale nutrient export data compilation, the primary objective of this study was to compile measured annual nitrogen (N) and phosphorus (P) load data representing field-scale transport from agricultural land uses. The resulting publicly available database provides nutrient load data and corresponding watershed characteristics from numerous field-scale studies. Because of its format and design, this populated database should provide readily accessible, easily queried information to support water quality management, modeling, and future research design. The database also establishes a platform allowing user input of additional project-specific data.

The original version of this database is currently being used in two projects evaluating land management impacts on water quality. In 2003, the USDA began a national project, the Conservation Effects Assessment Project (CEAP), to assess the environmental benefits of conservation practices implemented under 2002 Farm Bill. Within CEAP, USDA-NRCS, USDA-ARS, and Texas Agriculture Experiment Station scientists are conducting an assessment of conservation practice effects at the national scale (Mausbach and Dedrick 2004). The database is being used in CEAP to create site-specific data sets for calibrating and testing Agricultural Policy Environmental eXtender (APEX) model simulations (Williams et al., 1998) representing National Resources Inventory (NRI) data point locations across the country. APEX is being used to estimate nutrient and sediment loading at these locations for the CEAP National Assessment. Furthermore, the breadth of data contained in the database also provides a means of comparing physical relationships in observed data to those in simulated values.

The database is also in use for development and evaluation of a Bayesian version of the USGS SPARROW (SPAtially Referenced Regressions On Watershed Attributes) model (Smith et al. 1997). SPARROW relates in-stream water-quality measurements to spatially referenced characteristics of watersheds, including contaminant sources and factors influencing terrestrial and stream transport. The model empirically estimates the origin and fate of contaminants in streams, and quantifies uncertainties in these estimates based on model coefficient error and unexplained variability in the observed data. The Bayesian SPARROW model introduces the dynamic modeling of nutrient transport between sub-watersheds and uses a conditional autoregressive approach to explicitly account for spatial correlations not included in the stream networks (Qian et al. 2005). The current Bayesian SPARROW application was based on non-informative prior probability distributions for all the model parameters. The database will provide the basis for the prior probability distribution in the Bayesian SPARROW model, provide information for the relative plausibility of the various source coefficient values (betas in the usual SPARROW notation), and thus assist in model implementation and/or data-poor situations.

METHODS

Literature Survey (Data Compilation)

Data compilation involved a two-phased approach. First, data were compiled from the agricultural land use studies reported in Reckhow et al. (1980). Relevant studies conducted on cultivated agriculture and pasture/rangeland/hay land uses were collected, and nutrient load data with corresponding watershed characteristics were compiled. Then an extensive literature survey was conducted on additional and more recent published studies that reported measured annual N and P data from agricultural land uses. Only studies that appeared in peer-reviewed scientific journals were collected, thus the extensive amount of informal data (e.g. gray literature) was avoided. As a result, data included in the database appear in readily available studies that have received rigorous scientific review. In compiling relevant studies, a sincere effort was made to include all available studies conducted in the US that meet the criteria outlined in Table 1.

Table 1. Criteria used to select studies for database inclusion.

	Included	**Not Included**
Contributing land use	Single land use	Multiple land uses
Land use types	Cultivated agriculture	Forest
	Pasture/rangeland/hay	Urban
Contributing area (ha)	> 0.009	< 0.009 ha
Nutrients	N	K, Ca
	P	Mg, S
Study design	Annual nutrient loads	Nutrient concentrations
	Natural rainfall	Rainfall simulation
	Measured results	Modeled results
	Surface runoff	

Specifically, only measured annual N and P load data from field- and farm-scale studies were included. N and P were chosen because they often control biological productivity, which impacts dissolved oxygen levels in streams and lakes and overall aquatic ecosystem health (Sharpley et al. 1987). Nitrate and nitrite also impact drinking water quality and are listed as primary drinking water pollutants by the US Environmental Protection Agency (USEPA 2003). Data collected on periods shorter than one year were excluded because of the effect of temporal variability of weather, cropping patterns, and nutrient application on nutrient export. Data measured from multiple land use watersheds were not used because of the difficulty in determining the relative contributions from each land use; however, information on the relative contributions, integrated effects, and downstream transport deserve further research. Data from rainfall simulation studies were excluded in an effort to address only field-scale effects from natural rainfall and runoff mechanisms.

Database Development and Population

Watershed characterization, nutrient load, soil loss, and hydrology data were extracted from each publication that presented results meeting the previous criteria. These data were then entered into Microsoft Access 2000, and the resulting database was named “Measured Annual Nutrient loads from AGricultural Environments” or MANAGE. Generally, each database record was created from a single publication, but occasionally multiple publications with data from the same watershed(s) were used to create a record. Each record in MANAGE represents a watershed or watersheds with similar land management over a given time period and contains the following categories (headings):

1. Auto number - Automatically assigned identification number.
2. Watershed ID - Name of the watershed. If not specified, a watershed ID was assigned based on watershed management characteristics.
3. Location (City, State) - City and state/province of the study (occasionally only a county or region was specified).
4. State - US state (or Canadian province) included to aid state-specific queries.
5. Location (Lat, Long) - Latitude and longitude of the study.
6. Date - Beginning and end of period with annual nutrient load data (not necessarily the entire study duration).

7. Watershed years (ws yr) - Product of the number of monitored watersheds and the number of years with annual nutrient load data. Some temporal overlap occurred in studies at Chickasha, OK, and thus data from the coincidental studies were not separated.
8. Land Use - Identification of crop or vegetation type(s), crop rotations, grazing management, artificial drainage, and dryland or irrigated.
9. Tillage - Description of the tillage management divided into four options: no-till, conservation, conventional, or pasture. The first three options are intended to represent the dominant tillage management alternative for watersheds with cultivated crop production. Conservation tillage represents a range of practices design to leave crop residue on the soil surface. The pasture option represents rangeland, improved pasture and hayland; all of which may be grazed (indicated in the Land Use Category #8).
10. Conservation Practice 1, Conservation Practice 2, Conservation Practice 3 - Description of conservation practices used in the study watershed(s) divided into five options: waterway, terrace, filter strip, riparian buffer, or contour farming. This category was repeated three times to account for multiple practices used in conjunction.
11. Dominant Soil Type - Soil textural class and soil series. If only the soil series was specified, the USDA-NRCS "Official Soil Series Descriptions (OSD)" (USDA-NRCS 2005) available online at http://soils.usda.gov/technical/classification/osd/index.html was used to assign a textural class.
12. Hydrologic Soil Group - NRCS hydrologic soil group (HSG) classification (A, B, C, or D). The HSG was rarely specified, but it is an important general soil characterization that warranted inclusion. Therefore, the HSG was derived from Appendix 3B "Hydrologic Soil Groups" (Haan et al. 1994) and from the USDA-NRCS "Official Soil Series Descriptions (OSD)" (USDA-NRCS 2005) if the soil series name(s) was specified. The HSG was estimated from NRCS definitions as presented in Haan et al. (1994) if only the soil texture was specified.
13. Soil Test P (ppm) - Maximum and minimum soil test P values for records with multiple watersheds or multiple years.
14. Soil Test P Extractant **-** Extractant used to determine soil test P.
15. Land Slope (%) - Maximum and minimum land surface slopes for records with multiple watersheds.
16. Watershed Size (ha) - Maximum and minimum watershed sizes for records with multiple watersheds.
17. Fertilizer Formulation 1, Fertilizer Formulation 2 - Type of fertilizer applied. This category was repeated twice to account for multiple fertilizer formulations. The common name, chemical name, and/or macro-nutrient composition (given as % N-P-K) of the fertilizer(s) was input based on specified information.
18. Fertilizer Application Method 1, Fertilizer Application Method 2 - Fertilizer application method divided into four options: surface, injected, incorporated, or other. This category was repeated twice to account for the multiple formulations presented in the Fertilizer Formulation category #17.
19. Annual maximum, minimum, and average values are provided for the following categories when specified:
    a. N applied (kg/ha) - The total annual amount of N applied to watershed(s) from all fertilizer sources.

b. P applied (kg/ha) - The total annual amount of P applied to watershed(s) from all fertilizer sources.
c. Precipitation (mm).
d. Runoff (mm).
e. Soil loss (kg/ha) - The total measured soil loss from the watershed(s).
f. Dissolved N (kg/ha) - The total amount of N lost from the watershed(s) in a dissolved form.
g. Particulate N (kg/ha) - The total amount of N lost from the watershed(s) in a particulate form (associated with sediment).
h. Total N (kg/ha) - Total N load was specified in a number of the publications. If the total N load was not specified, it was determined as the sum of dissolved and particulate N loads, when both were specified.
i. Dissolved P (kg/ha) - The total amount of P lost from the watershed(s) in a dissolved form.
j. Particulate P (kg/ha) - The total amount of P lost from the watershed(s) in a particulate form (associated with sediment).
k. Total P (kg/ha) - Total P load was specified in a number of the publications. If the total P load was not specified, it was determined as the sum of dissolved and particulate P loads, when both were specified.
l. Form - Specific form or laboratory analysis technique used to determine dissolved, particulate, and total N or P composition in runoff.

20. Total, Surface, Baseflow Indication - Indication of the flow transport mechanisms addressed; however, annual loads were input only for runoff water leaving the watershed(s). Runoff may include storm runoff as well as baseflow contributed by seepage (re-emergence of lateral subsurface flow) and was identified as such when specified. Data on subsurface water quality were not analyzed but were indicated in this category. Results on "drainage" from artificially drained watersheds were included only in the notes section.
21. Comments - Additional information. Examples include: subsurface loads from areas with artificial drainage, supporting publications, data estimation procedures, and missing data.
22. Reference - Complete citation of each publication used to develop the database record.

The most difficult aspect of populating the database was dealing with various formats of N and P load data presentation in the publications. In certain publications, nutrient loads were presented only in figures without corresponding numerical values. Although this format aided in visual comparison of treatments, it necessitated estimation of nutrient load values. The numerous and varied methods of tabular data presentation created additional difficulty. In the collected studies, data were reported with various formats of time (e.g. seasonal, annual, annual mean); watershed (e.g. individual watershed, treatment specific); nutrient form (e.g. dissolved/soluble N and P, particulate N and P, total N and P, NO_3-N, NH_4-N); and analytical method used. For "total" nutrients, it was often not clear whether the digestion or other analytical method was performed on the water, soil, or the combined sample. Faced with these various formats, necessary calculations and estimations were made to produce mean, maximum, and minimum annual nutrient loads, which were entered into the database. Because of these difficulties and the possibility of errors in estimating values and gleaning data from publications, users should exercise caution when basing decisions and recommendations on these data. We suggest that data of interest be confirmed with the original source prior to drawing consequential conclusions.

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Data Analysis

After relevant studies were collected and appropriate data were compiled and entered into the database, a limited number of general summary and comparative analyses were conducted. Watershed information was summarized to illustrate the distribution of study site characteristics. Specifically, location, land use (crop type), tillage management, conservation practices, soil textural class, watershed size, and fertilizer formulation were analyzed. The data distributions were tabulated based on watershed years (ws yr) because this format represented the data distribution better than alternatives such as: number of studies, records, or watersheds. When % values are reported, they represent the % of ws yrs represented by that characteristic, unless otherwise noted.

Annual nutrient load data were then evaluated by several methods. Where applicable, potential linear relationships between nutrient loads and selected field characteristics were evaluated with regression analyses. Nutrient loads were compared to watershed size to explore the impact of scale and were compared to nutrient application rate to evaluate the direct effects of fertilizer application. Dissolved, particulate, and total P loads were also compared to soil test P levels. The effects of tillage, conservation practices, soil textural class, and land use on annual N and P loads were also compared. Graphical procedures were used to examine and display potential differences for each treatment, and statistical differences in median annual loads were determined with Mann-Whitney tests.

All statistical tests were performed with Minitab 13 software and procedures described in Minitab (2000), Helsel and Hirsch (1993), and Haan (2002). All tests of significance were conducted at an *a priori*, $\alpha = 0.05$, probability level. As stated previously, annual nutrient load data were presented with a variety of formats in the various publications. From these varying data sets, annual mean, maximum, and minimum values were determined and used to populate the database. Because individual annual values were not available for all of the watersheds, the statistical comparisons do not strictly adhere to all rules and assumptions of standard statistical design. Therefore, the statistical results are presented for general comparative purposes only.

RESULTS AND DISCUSSION

Measured annual nutrient load data from 40 publications (listed in Table 2) were entered into a Microsoft Access 2000 database. The resulting 163-record MANAGEv1 database contains approximately 1100 ws yrs of annual N and P loads. Updated versions of the database that include future studies and previous studies that were inadvertently overlooked will be made available as warranted.

Study Site Characterization

Measured annual nutrient load data were obtained from fifteen US states (Table 3) and two provinces in Canada. The Canadian data were included to help fill in geographic gaps in the northeastern and northwestern US. Texas and Oklahoma contributed the most data, but the southeast and central states were also well represented. No data were available from the Pacific Northwest, Rocky Mountains, or New England States. Watersheds established and/or operated by USDA-ARS, which were designed to provide long-term data collection necessary to address temporal and spatial variability, provided more than 830 ws yrs (75%) of annual nutrient load data. A majority of the ARS data was collected from watersheds located in Treynor, IA, Coshocton, OH, Riesel and Bushland, TX, Tifton, GA, Morris, MN, and El Reno, Woodward, and Chickasha, OK.

Table 2: Refereed publications presenting measured annual N and/or P load data meeting the criteria listed in Table 1.

Publication (short ref.)	**Publication (short ref.)**	**Publication (short ref.)**
Alberts et al. 1978.	Jones et al. 1985.	Schuman et al. 1973b.
Alberts and Spomer. 1985.	Kilmer et al. 1974.	Sharpley. 1995.
Angle et al. 1984.	Kissel et al. 1976.	Steinheimer et al. 1998a.
Berg et al. 1988.	Lee et al. 2003.	Steinheimer et al. 1998b.
Burwell et al. 1974.	Long. 1979.	Tate et al. 1999.
Burwell et al. 1975.	McDowell and McGregor. 1980.	Thomas et al. 1968.
Chichester and Richardson. 1992.	Menzel et al. 1978.	Udawatta et al. 2002.
Drury et al. 1993.	Nicholaichuk and Read. 1978.	Udawatta et al. 2004.
Edwards et al. 1996.	Olness et al. 1975.	Vervoort et al. 1998.
Grigg et al. 2004	Olness et al. 1980.	Vories et al. 2001.
Harmel et al. 2004a.	Owens et al. 2003.	Weidner et al. 1969.
Harmel et al. 2004b.	Pierson et al. 2001.	Wood et al. 1999.
Harms et al. 1974.	Schuman et al. 1973a.	Young and Holt. 1977.
Jackson et al.1973.		

Table 3: Locations of studies with measured annual N and P load data that meet the criteria in Table 1.

US States	**Watershed Years**	**Number of studies**
Alabama	24	2
Arkansas	24	2
California	19	1
Georgia	93	4
Iowa	105	8
Louisiana	16	1
Maryland	6	1
Minnesota	109	3
Missouri	27	1
Mississippi	10	1
North Carolina	8	1
Ohio	132	2
Oklahoma	268	5*
South Dakota	14	1
Texas	200	6*
Canadian Provinces		
Ontario	24	1
Saskatchewan	24	1
Totals:	1103	40

* One study analyzed nutrient losses from sites in both Oklahoma and Texas

Land use fit well into three general categories: cultivated crops, pasture/rangeland/hay, and various rotations (Fig. 1). Cultivated crops made up the largest category contributing 41% of the data. Data from fields with corn production provided 22% of the annual nutrient load data, oats/wheat contributed 10%, and other crops including cotton, peanuts, soybeans, and sorghum contributed 1-2% each. The pasture/rangeland/hay category, which includes uncultivated grazed, ungrazed, and hayed land uses, provided 33%. Data from pasture (assumed to represent improved pasture) provided 16%, native prairie grasslands contributed 10%, managed rangeland 4%, and alfalfa 2%. The various rotations category, which represents a wide range of land use conditions, contributed 27% of the data. This category contains data that were presented based on rotation behavior as a whole; therefore, individual annual values representing each crop within the rotation were not specified.

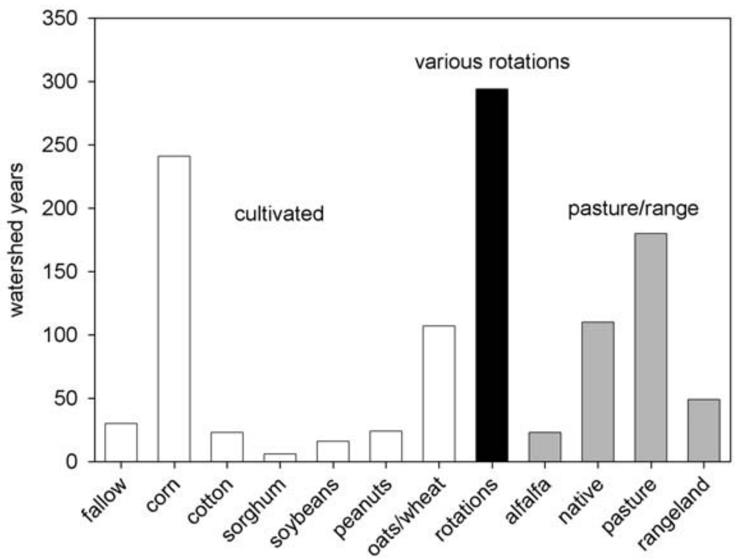

Figure 1: Distribution of annual nutrient load data based on watershed years for each land use category and crop type.

Data for a wide range of tillage management conditions were obtained (Fig. 2). Conventional tillage management sites provided the most annual nutrient load data (42%). Sites with conservation tillage provided 16%, and no-till provided 9%. Uncultivated sites in the pasture/rangeland/hay land use category contributed 33%. Conventional tillage was utilized almost exclusively on studies from the 1940's through the 1960's. In the 1970's, data were collected under mostly conventional and conservation tillage but also under limited no-till management. By the 1980's and 1990's, conventional, conservation, and no-till management were all being actively studied. Summary data for conservation tillage are presented here and thus are not included in conservation practice discussion even though conservation tillage is widely accepted as an effective conservation practice.

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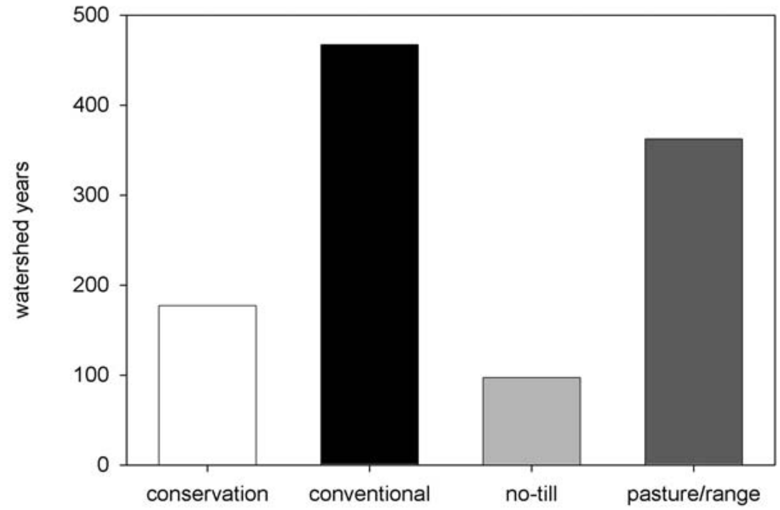

Figure 2: Distribution of annual nutrient load data based on watershed years for each tillage category.

Much of the nutrient loss data was collected on fields with no conservation practices (although 16% occurred under conservation tillage as discussed previously). Approximately 24% of the data occurred on areas with at least one conservation practice, and 15% occurred on fields with more than one conservation practice (Fig. 3). Sites with contour farming provided 20% of the data, grassed waterways provided 14%, terraces 10%, and filter strips and riparian buffers less than 5% each.

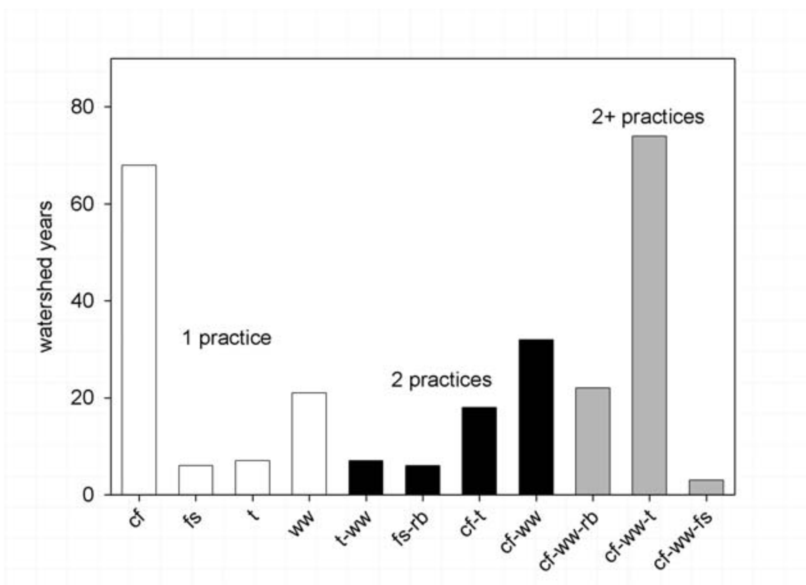

Figure 3: Distribution of annual nutrient load data based on watershed years occurring on fields with various conservation practices (contour farming - cf, terrace - t, waterway - ww, riparian buffer - rb, filter strip - fs).

Data were available for a wide range of soil textures from heavy clays in the Texas Blackland Prairies to sandy soils in the Southern Coastal Plain. Sites with loamy soils contributed the most data (Fig. 4). Soils in the loam and silt loam soil textural classes contributed 24% and 40% respectively, but sites with fine textured clay loam (9%) and clay soils (11%) also contributed substantial data. Similarly, the distribution of data was dominated by sites with hydrologic soil groups B (62%), which have moderate infiltration rates and textures, and D (18%), which have high runoff potential and fine textures.

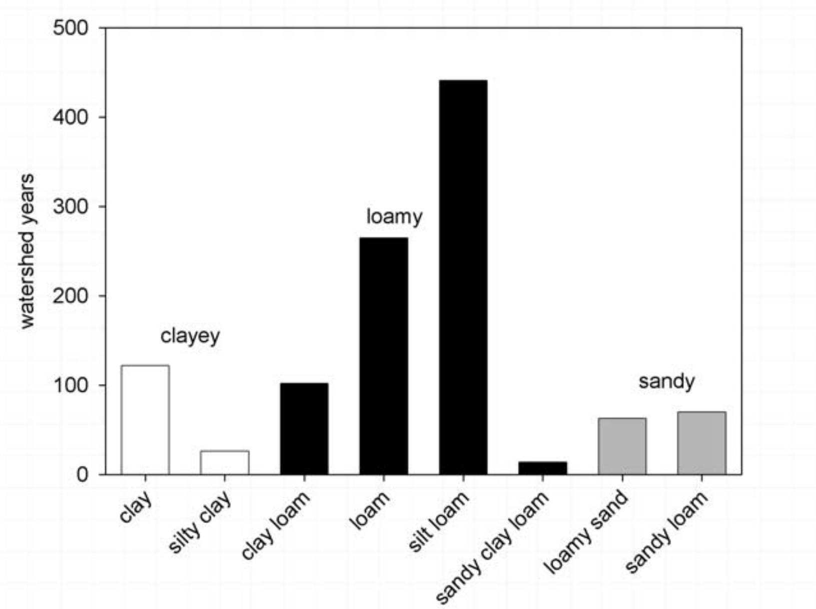

Figure 4: Distribution of annual nutrient load data based on watershed years for each soil textural classes.

Much of the compiled annual nutrient load data was collected on watersheds less than 10 ha (Fig. 5). This result is attributed to the single (homogeneous) land use criteria for including measured data in this database. Small plot and field-scale studies are typically designed to evaluate conditions with homogeneous land use, which explains the predominance of small watersheds. The likelihood of heterogeneous land uses, which were excluded in this compilation, increases as watershed size increases.

Many fertilizer management strategies were used on the study sites as illustrated in Figure 6. Inorganic fertilizers were most commonly applied (52%), but several different formulations were used, and the formulation was often unspecified (15%). Organic fertilizer (poultry litter, cattle manure) application occurred in only 8% of the ws yrs. No fertilizer was applied in many cases (26%), but mostly under fallow, grazed, and native prairie grassland conditions. Surface application without incorporation accounted for 25% and with incorporation for 23%, but often the method of fertilizer application was not specified (47% of ws yr). Fertilizer injection occurred on 5% of the ws yrs.

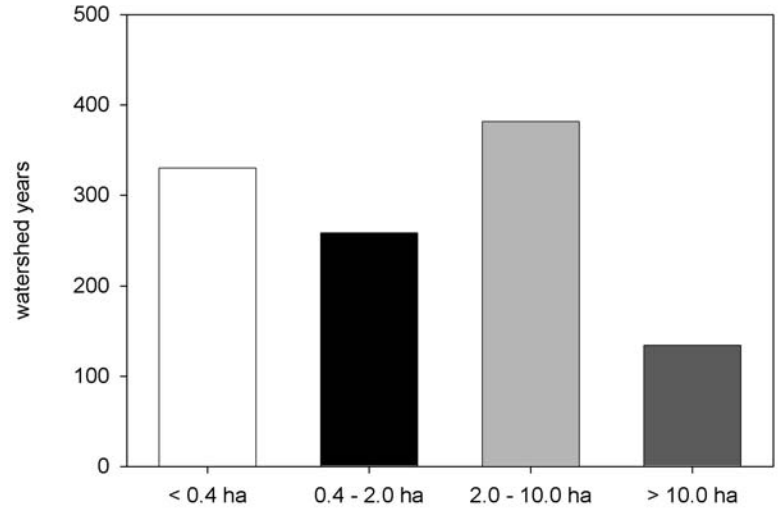

Figure 5: Distribution of annual nutrient load data based on watershed years for various watershed sizes.

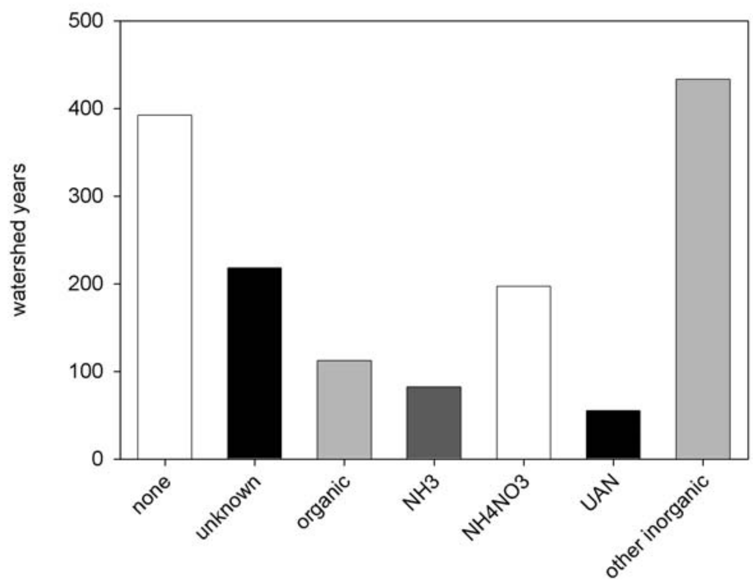

Figure 6: Distribution of annual nutrient load data based on watershed years for various fertilizer types. The sum of watershed years exceeds 1103 because a combination of fertilizer formulations was often used.

Nutrient Load Comparisons

Annual N loads exhibited no significant linear relationships with field size; however, dissolved, particulate, and total P loads all significantly decreased as field size increased. Although these relationships are significant, considerable variability existed (all adjusted R^2 values < 0.07). The results for N were expected because fields were defined in this study as units of homogeneous land use and management, particularly nutrient management. In contrast, reduction of nutrient loads, on a per area basis, would be expected for larger mixed land use watersheds, as the entire watershed would not typically receive fertilizer application. Possible causes for decreasing P loads with increasing watershed size include: *dilution* as an increasing amount of baseflow contributes to watershed export, *landscape processes* as infiltration, re-adsorption of soluble P in runoff, and re-deposition of eroded sediment with particulate P increase, and *channel processes* as the role of channel sediments in regulating P concentrations increases as size increases (Sharpley et al. 1999, Sharpley et al. 2002).

In terms of annual loads, only dissolved N was significantly related to application rate. Considerable variability existed between all of the N and P forms and nutrient application rate (all adjusted R^2 values < 0.08), but annual dissolved N loads did increase with increasing N application. The lack of correlation between application rate and particulate N, total N, and all forms of P loads can be attributed to the overriding effect of soil erosion and transport on particulate N and P loss in certain situations (Sharpley et al. 1987, Harmel et al. 2004b). Particulate N and P losses contributed, on average, three times as much as corresponding dissolved forms. Differences in runoff volumes, soil interaction, plant uptake, watershed physical characteristics have also been shown to contribute to nutrient loss variability (e.g., Sharpley et al. 1987, Pote et al. 1996, Harmel et al. 2004b) and to dampen the effect of application rate.

Significant linear relationships were evident between soil test P and dissolved, particulate, and total P loads, although the variability was quite large with adjusted $R^2 < 0.19$ (Figure 7). Although numerous researchers have determined that soil test P is related to P in runoff (e.g. Pote et al. 1999, Sharpley et al. 1999, and Torbert et al. 2002), such studies focused on P concentrations not P loads because load analysis is subject to the confounding influence of differing runoff volumes (e.g. Pote et al. 1996). Recent manure/litter applications have also been shown to temporarily weaken or overwhelm the relationship between soil test P and runoff P concentrations (Sharpley and Tunney 2000, Pierson et al. 2001), although two recent field-scale studies yielded contrasting results regarding the relative importance of manure applied P and soil test P on annual dissolved P loads (Harmel et al. 2005, DeLaune et al. 2004). The relative contribution of recently-applied nutrients and nutrients in the soil profile affects the environmental impact of agricultural P and thus deserves further research and management consideration (Sharpley et al. 2002).

Several results differed from commonly accepted behavior in the comparison of median annual nutrient loads for the various management practices. These unusual results, however, were not surprising because nutrient loads were grouped across widely varying site characteristics including soil texture, slope, crop, tillage, fertilizer, rainfall, and conservation practices. The studies compiled also differed in the type of nutrient load data collected. Specifically, numerous combinations of dissolved, particulate, and total nutrient load data and various analytical tests were reported. Differences in runoff also tend to confound nutrient load results, thus nutrient concentrations are also commonly examined. Although these confounding influences created difficulty in drawing strong conclusions across varying conditions, they support the need for a database such as MANAGE that allows users to select only relevant data.

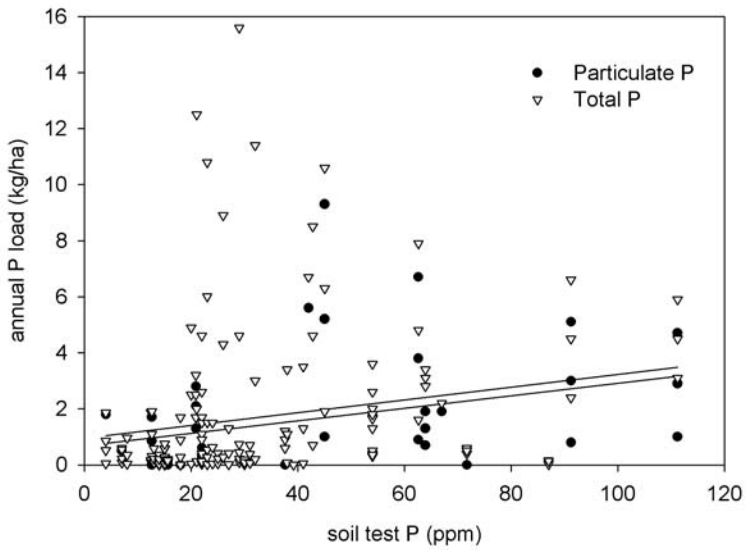

Figure 7: Scatter plot and regression lines for soil test P levels and particulate and total P loads.

The influence of tillage on nutrient loads is shown in Table 4. Median particulate N loads for sites with conventional tillage exceeded those from conservation tillage and no-till sites as expected with increased soil erosion (Fig. 8). In contrast, particulate P loads were not significantly different between conventional, conservation, and no-till tillage management. Dissolved N and P loads were highest for no-till management probably because fertilizer is not incorporated. Median N and P loads from cultivated conditions tended to exceed those from pasture/range/hay because the non-cultivated sites typically received less fertilizer and have permanent vegetative cover. Figure 9 illustrates the potential of extreme dissolved P loads when excessive manure is surface applied (unincorporated) in pasture settings. These large P loads occurred in years with high poultry litter application rates and continued due to residual soil P in years when only N was applied (Pierson et al. 2001). Large P loads can also be experienced in cultivated conditions in spite of incorporation when high rates of manure are applied (Weidner et al. 1969).

The effects of conservation tillage were discussed with other tillage management options; therefore, conservation tillage is not included in the following discussion of conservation practices, such as waterways, terraces, riparian buffers, and filter strips. The influence of conservation practices on nutrient loads was more variable than tillage impacts (Table 4). In this analysis, the data were expected to show reduced total and particulate nutrient loads with conservation practices; however, while conservation practices did reduce nutrient loads in specific studies (e.g. Lee at al. 2003, Udawatta et al. 2002), no clear tendency was shown in the overall data (Fig. 10). The reduced impact of conservation practices can be attributed to varying site characteristics, differences in load data collected and analytical tests used, and probably most importantly, the tendency to establish practices in conditions vulnerable to erosion and nutrient loss.

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Table 4. Median annual dissolved, particulate, and total N and P load values (kg/ha) for selected treatments.

Treatment*	Total N (kg/ha)	Diss. N (kg/ha)	Part. N (kg/ha)	Total P (kg/ha)	Diss. P (kg/ha)	Part. P (kg/ha)
Tillage						
Conventional	7.88a	2.41a	7.04a	1.05a	0.19b	0.64a
Conservation	7.70a	2.30ac	3.40c	1.18ac	0.65ac	1.00a
No-Till	1.32b	4.20c	1.80bc	0.63c	1.00c	0.80a
Pasture/Range	0.97b	0.32b	0.62b	0.22b	0.15b	0.00b
Conservation Practice						
None	2.19a	1.60a	1.70a	0.41a	0.26ab	0.64ab
One Practice	6.73b	1.33a	14.80a	0.61ab	0.14a	0.37a
2+ Practices	8.72b	2.61b	3.30a	1.22b	0.50b	0.75b
Soil Texture						
Clay	4.93a	4.47a	2.00a	0.92a	0.50a	0.55a
Loam	4.05a	1.64b	5.78b	0.41b	0.18b	0.93a
Sand	2.74a	1.70ab	-**	1.50ab	0.07ab	-**

* For each nutrient form within a treatment, medians followed by a different letter are significantly different ($\alpha = 0.05$).
** No particulate N or P data were available for sandy soils.

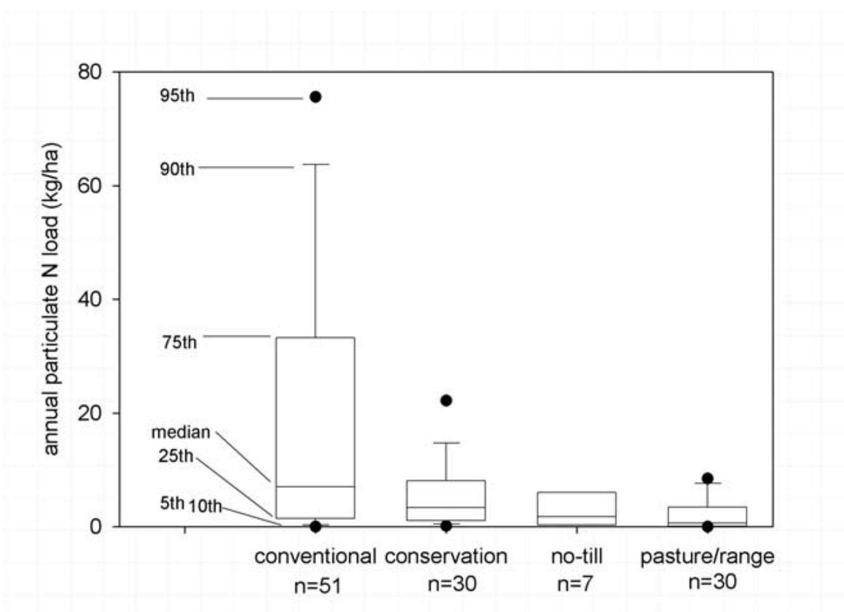

Figure 8: Annual particulate N loads under various tillage management alternatives.

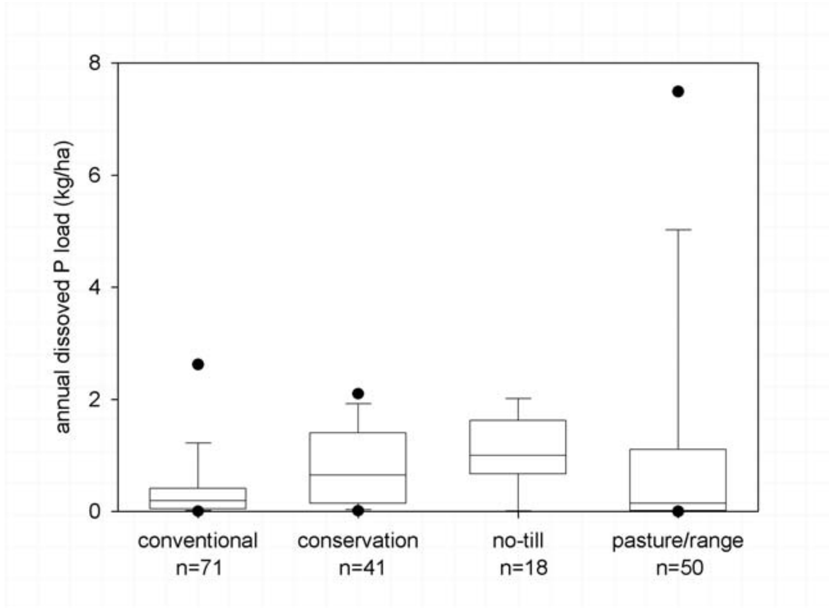

Figure 9: Annual dissolved P loads under various tillage management alternatives.

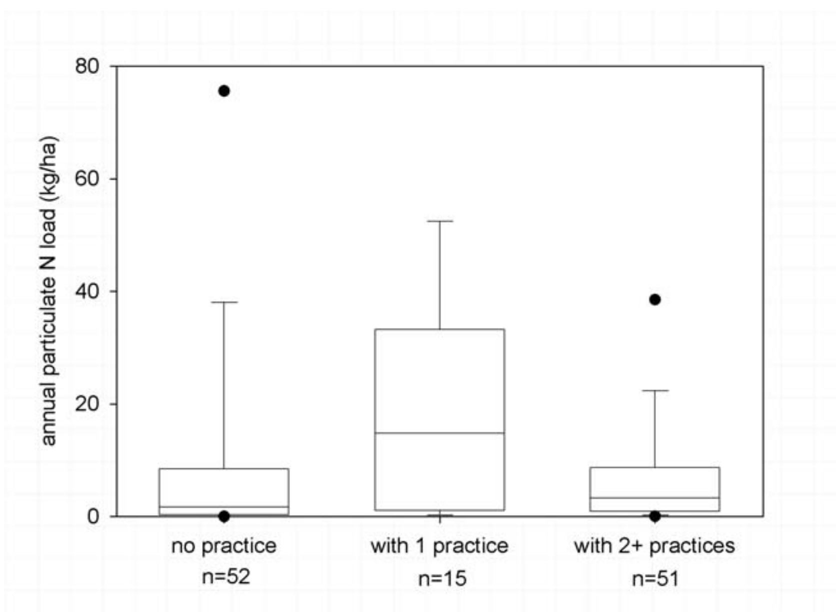

Figure 10: Annual particulate N load data with and without conservation practices.

Gitau et al. (2005) compiled an interactive database tool for determining best management practice (BMP) effectiveness based on site characteristics. The present database linked to such BMP tools would provide measured data with which to estimate and compare conservation practice effectiveness. Although considerable data are available on conservation practice effectiveness, the need to quantify and better understand their watershed-scale performance is crucial. This need is illustrated by a recent USDA commitment and initiation of the Conservation Effects Assessment Project (CEAP) as described in Mausbach and Dedrick (2004).

In terms of the effect of soil texture on nutrient loss, the same interesting result occurred for dissolved N and P and total P. In each case, neither clay and sand nor loam and sand were significantly different, but clay and loam were significantly different (Table 4). It was expected that clay and sand would differ most in behavior because of drastic differences in particle size distribution and nutrient transport mechanisms.

The comparison of nutrient loads across the various land uses (crop types) was made difficult by differences in the amounts of data available for each land use. As shown previously in Figure 1, corn, oats/wheat, various rotations, and pasture/range/hay, all provided substantial data (each in excess of 100 ws yr). Each of the other land uses provided less than 30 ws yrs. These differences in data availability should be considered in the following discussion. For dissolved N, sites in corn production tended to have quite large and variable annual loads (Fig. 11). Cotton, soybeans, and various rotations also had relatively high dissolved N loads. The largest median particulate N loads occurred under corn, cotton, and soybean production (Table 5), but the largest variability occurred under fallow conditions (Fig. 12), which is attributed to the extreme erosion potential for clean cultivated fallow conditions. Annual total N loads were largest for corn, cotton, and oats/wheat.

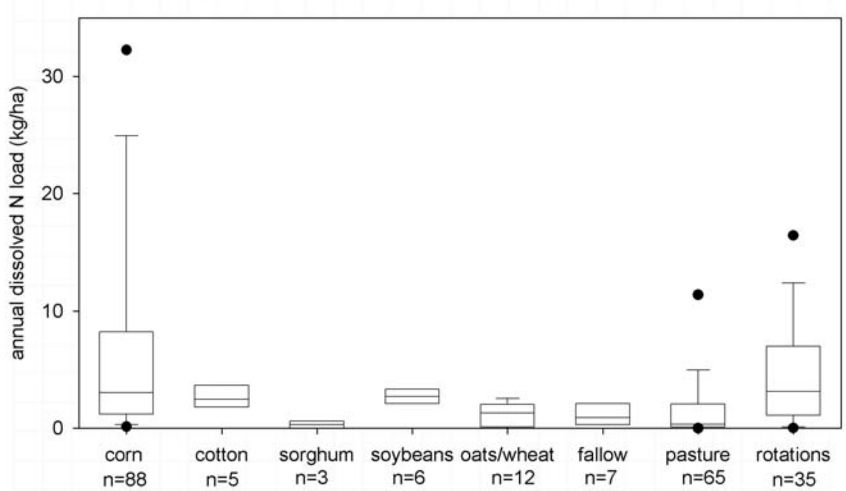

Figure 11: Annual dissolved N loads for each land use category (no data were available for peanuts).

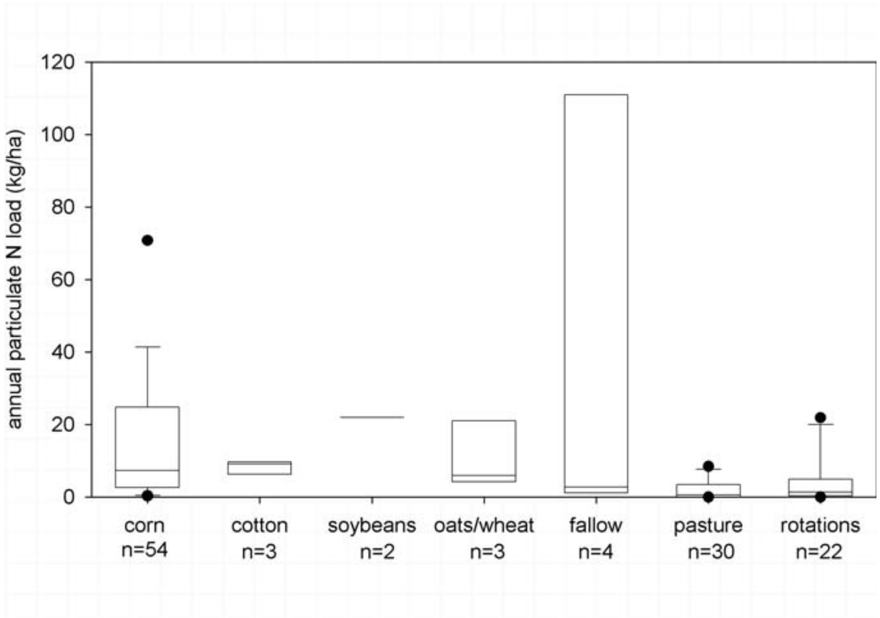

Figure 12: Annual particulate N loads for each land use category (no data were available for peanuts or sorghum).

Land use had relatively little impact on median annual dissolved P loads, as values were less than 1.0 kg/ha for all land uses (Table 5). In contrast, land use did affect the variability of dissolved P loads (Fig. 13). Dissolved P loads for the various rotations category were quite variable due to the diversity of cropping systems included. Dissolved P also exhibited considerable variability for pasture/rangeland/hay because of the differing fertilizer management ranging from none applied on rangeland to high litter application rates on improved hay/pasture. Particulate P loads were quite large for cotton, soybeans, and oats/wheat, but these results were based on two or fewer data points (Fig. 14). The fallow sites again demonstrated the potential for high erosion and corresponding particulate P loss. Total P loads were largest for cotton and oats/wheat, but large annual loads occurred from several land uses.

Table 5: Median annual total N and P load values (kg/ha) for land use (crop type) treatments.

Treatment	**Total N (kg/ha)**	**Diss. N (kg/ha)**	**Part. N (kg/ha)**	**Total P (kg/ha)**	**Diss. P (kg/ha)**	**Part. P (kg/ha)**
Land use						
Corn	18.70	3.02	7.27	1.29	0.22	0.85
Cotton	7.88	2.47	9.13	5.01	0.68	5.60
Sorghum	3.02	0.30	-	1.18	-	-
Peanuts	-	-	-	-	0.05	-
Soybeans	-	2.70	21.9	0.45	0.60	9.60
Oats/Wheat	6.61	1.31	5.90	2.20	0.30	3.45
Fallow Cultivated	3.00	0.90	2.70	1.08	0.48	0.45
Pasture/Range	0.97	0.32	0.62	0.24	0.15	0.00
Various Rotations	3.68	3.12	1.36	0.59	0.80	0.60

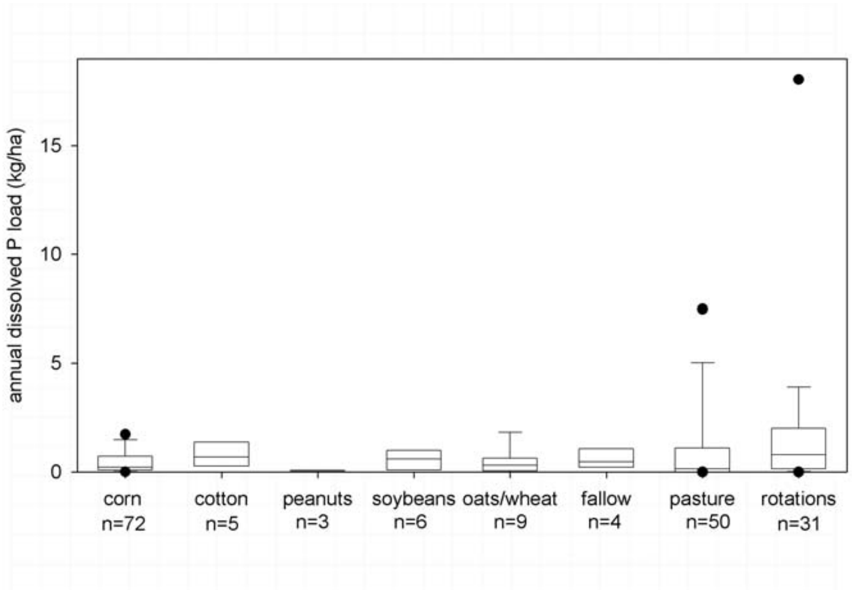

Figure 13: Annual dissolved P loads for each land use category (no data were available for sorghum).

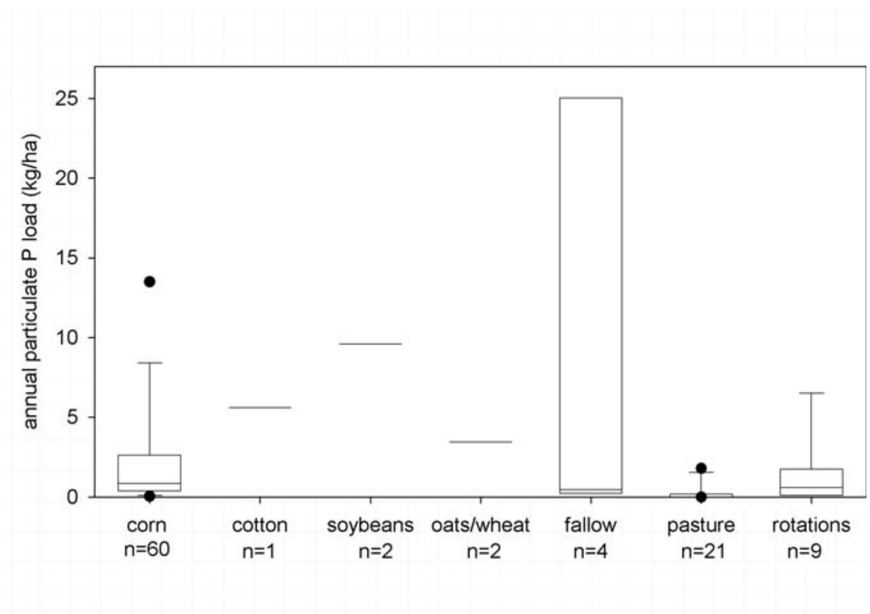

Figure 14: Annual particulate P loads for each land use category (no data were available for peanuts or sorghum).

SUMMARY

Several interesting results were evident in the evaluation of N and P load data included in the MANAGE database. Certain results were expected, but others differed from commonly accepted nutrient transport behavior. These unusual results are attributed to grouping nutrient load data across widely varying hydrologic and management conditions and to differing data availability for various management alternatives. The compiled studies also differed in the type of annual nutrient load data collected (dissolved, particulate, and/or total). While these confounding factors contributed to unusual results, they supported the need for such a tool that facilitates the selection of data representing conditions of interest.

Although selected statistical analyses of nutrient loads are presented in this study, the primary value is its presentation of a publicly available database compilation of a majority of the measured annual nutrient load studies conducted on agricultural land uses in the US. Our goal was that MANAGE will: 1) facilitate the evaluation of model performance in watersheds or conditions with limited measured data and thus improve model reliability, 2) provide user-friendly data query capabilities that readily produce comparative measured data for site-specific applications, 3) illustrate the type and quantity of data available for watersheds, regions, and conditions of interest, 4) establish a platform that allows the user to input additional project-specific data, and 5) direct future nutrient transport research.

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